AI & Food Systems: The Future of the Canadian Economy

by

Thomas Changarathil

Submitted to OCAD University in partial fulfillment of the requirements for the degree of Master of Design in Strategic Foresight & Innovation

Toronto, ON, Canada, 2022

ABSTRACT

This major research project explores the problem space of food systems driving climate change and climate change in turn, threatening the resilience of food system infrastructure and food security in Canada. A literature review covers the problems space in more detail, and potential solutions in the circular economy framework and the strategic application of AI. Synthesis of the literature review with an expert-informed Three Horizons workshop generated strategic intervention points for AI to address food system resilience and security while driving progress towards circularity. An affinity mapping exercise on the data from Horizon Three, which represent a co-envisioned future food system for Canada led to the development of a novel framework to align desired outcomes for future food systems with the core values workshop participants co-developed. This framework – LASERRS (Localism, Accessibility, & Ethics for Regeneration, Resilience, and Security), can provide a map to orient future research, development, projects, and policies in food systems such that it aligns with the values and desired co-envisioned by workshop participants.

ACKNOWLEDGEMENTS

I'd like to thank my friends and colleagues for their support throughout the past two years as I completed the SFI program. A special thanks to those who volunteered their time and knowledge for this project. Thank you to my advisor, Dr. Michele Mastroeni for the consistent support and throughout this year-long research journey, and for the helpful feedback and advice – you helped me navigate and make sense of the complexity inherent in this project.

A huge thanks to my partner, Marilyn, for your patience, love, and support – it means the world.

DEDICATION

For my late Godfather, Mathews Changarathil.

Table of Contents

LIST OF TABLES & FIGURES

Section 1 - Introduction

The linear model of current urban food systems in Canadian cities drives significant greenhouse gas emissions and therefore contributes to anthropogenic climate change and its associated impacts. These impacts include increasing average global temperatures, more frequent wildfires, rising sea levels, dwindling biodiversity, more frequent extreme weather events (such as hurricanes and tropical storms), increased droughts, and a loss of food security worldwide (IPCC, 2022). Cities drive much of these emissions since they are major population and economic hubs that demand significant resources to support their inhabitants (Trotta, 2022; United Nations, n.d.). Food, being a basic need, is among the most crucial of these resources. The vital role food systems play is why they are included among Canada's critical infrastructure. However, this poses a major issue in that food systems themselves are driving the loss of food security due to climate change. This negative reinforcing feedback loop will be further exacerbated as urbanization trends continue to increase city populations worldwide, including in Canada (Statistics Canada, 2022). Therefore, the demands on urban food systems in Canada will continue to increase as populations grow. The status quo of food systems consists of environmentally unsustainable food production practices and demand for food increasing in growing cities as food security (and supply) dwindles in the face of climate change. This poses a real threat to Canada's food security and presents an opportunity to re-think the design of food systems, and the role cities could play in the future of Canadian food systems.

The circular economy, a concept on the basic principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems, offers a paradigm that can address many of the systemic issues in our food systems that are driving negative environmental outcomes. Current linear food systems are wasteful, polluting, and ecologically degenerative. In contrast, circular food systems offer the potential for increased GDP growth through lower production costs and new economic opportunities. By shifting mental models from the linear paradigm, towards systems thinking, circular food systems empower stakeholders of all levels to thrive in a regenerative context.

Artificial Intelligence (AI) is a valuable tool that can accelerate the transition towards a circular food system, by harnessing its demonstrated capabilities in pattern recognition, prediction, optimization, planning, and robotic integration. These capabilities enable AI to support the design, operation, and optimization of circular products, businesses, and infrastructure (Ellen MacArthur Foundation, 2019). This project will further explore the strategic interventions for AI in the transition towards circular food systems, through a literature review and expert workshop.

This major research project has two goals:

1. It seeks to inform businesses and policymakers in identifying strategic intervention points that can generate economic value and enable resilient and secure urban food systems
2. It explores the above through the primary research question: How might AI accelerate the transition towards circular urban food systems in Canada?

Our future requires economically resilient and secure urban food systems as an alternative to the status quo, which produces significant waste, greenhouse gas emissions, and suffers from price sensitivity due interdependent factors like inflation, complex supply chains, geopolitical events, and pandemics. In the context of food systems resiliency can be interpreted as the ability of the system to “bounce back" from shocks and continue delivering what it’s supposed to (food to people), despite volatile environments. Food security refers to the availability and access to food for a population. In Canada, this means a greater focus on accessibility, since this factors in the food costs, and affordability. Therefore for Canadian food systems, resiliency must enable access both in terms of distance and affordability, and availability of food despite threats such as climate change, geopolitics, interconnected global supply chains. Circular food systems offer hope in designing food systems which can empower cities to thrive economically and environmentally. Many Canadian cities are taking the initial steps to begin the transition towards circular economies. However, it's uncertain if progress is fast enough to keep up with the rapidly destabilizing environmental and global contexts. Artificial intelligence holds the potential to accelerate this transition if it is strategically applied and harnessed by policymakers and businesses.

This research project collected data on current applications and research on AI, its applications to urban food systems, and case studies on applications of AI within circular economic frameworks through a literature review. Preliminary findings from the literature review suggested several use cases to integrate AI research and talent from research hubs in Canada, into urban food systems through enhanced local farming technologies, better designed food products, and more efficient food manufacturing and distribution operations. These findings added to data gathered from a Three Horizons workshop, during which subject matter experts in artificial intelligence, urban food systems, design, and foresight mapped out the status quo of our food systems and developed a vision for future Canadian food systems. A synthesis of literature review and workshop data highlighted strategic options to harness AI to accelerate transitions to circular food systems within a Canadian context.

This research will contribute to a growing body of literature on AI applications for sustainable futures and the circular economy by exploring the problem space with a futures approach and within a Canadian context. It can specifically inform and support decisions that policymakers, businesses, and sustainable investors make by highlighting key leverage points for strategic AI interventions to accelerate progress towards circular goals and to enable a more resilient and secure food system.

Section 2 - Methodology

This project seeks to generate strategic intervention points that can inform businesses and policy-makers in capturing economic value from resilient and secure urban food systems. To accomplish this objective, data collection centered around secondary research through a literature review and primary research through a Three Horizons Workshop. Combining these two research methods enabled a synthesis process from which an expert-informed systemic perspective of the Canadian food system emerged, and creative solutions to enable resilience and security were gathered from a diverse and interdisciplinary workshop group.

Literature Review

The literature review explored the current state of food systems in Canada and its relationship with food security challenges and climate change. This exploration provided context of the problem space and framed a review of research on artificial intelligence and the circular economy concept. The literature review was selected as one of the primary means of data collection for this project to leverage the breadth of published literature on a broad range of interlinked topics (artificial intelligence, food systems, food security, and the circular economy). This process also fed into the Three Horizons Framework by providing a snapshot of the status quo of Canadian food systems, some of its vulnerabilities, and its challenges.

Three Horizons Workshop

The Three Horizons framework was selected as it is well suited for this exploration of systems innovation, and is rooted in an exploration of current systems, their flaws, and the path towards a desired future system, and ideation of innovation opportunities in the path towards the future. Workshop participants were selected based on their subject matter expertise, and their familiarity with the tools and themes explored in this project. The workshop consisted of a total of 9 participants, some of whom had an expertise in multiple fields relevant to this project. The participant group contained experts and practitioners with backgrounds in artificial intelligence (2), emergency management & critical infrastructure planning (1), agri-food production (1), urban agriculture (1), circular design methods (1), and biotechnology (1). It also included individuals with a general interest in sustainable food systems and a background in design and foresight methods (2).

Three Horizon's is also a tool well-suited for beginners to futures thinking (such as subject matter experts in other fields) and is able to guide participants to powerful conclusions about the present, an inspiring co-developed vision for the future, and potential innovations to make that desired future a reality. Since this research project sought to identify strategic AI interventions to accelerate progress towards circular food systems in Canada by leveraging subject matter knowledge in artificial intelligence and food systems, this tool appeared to be well suited to the project goals.

Three Horizons prompts individuals and groups to consider the future through the perspective of three distinct horizons. Each horizon plays a role in co-envisioning a desired future and developing strategic options to transform current systems and their underlying paradigms into ones that enable our desired future to come into fruition. The mix of creative thinkers (design & foresight background) with more entrepreneurial and managerial perspectives (domain experts) among participants aligns with the goals of the Three Horizons process, which taps into these distinct mindsets to generate creative options to generate and capture value while moving from a flawed and unsustainable current state to a desired future. In the context of this project, the goal for the workshop would be to identify the issues plaguing our current food systems, define a future food system that would enable resilience and security, and generate possible opportunities for food systems innovations that either improve the issues of the current state or actively disrupt and transform our current systems closer to our desired future food system.

Horizon One

The Horizon One section of the workshop explores the status quo of the system under focus - in this case, the Canadian food system. The workshop questions in this section first prompts the group to contextualize the status quo by identifying its foundational values and priorities and the pillars which lie upon this foundation by exploring defining features and patterns of behaviours that govern the current Canadian food system. The final set of questions in the Horizon One section, prompt the group to consider the outcomes of the status quo by considering how the food systems currently impact the world around it, how it is threatened, and what might happen if we don't make changes to our food system.

Taken together, the themes extracted from the Horizon One discussion will define the context of our current food systems and indicate the implications of the status quo in the present and future. The information generated during the Horizon One conversations informed the synthesis process that identified an emergent system representing the status quo, its driving forces, components, impacts, and outcomes that threaten food system resilience and security.

Horizon Three

The Horizon Three section of the workshop explores a desired future for the area of focus - in this case, the Canadian food system. The Horizon Three questions prompted participants to collaboratively discuss their vision for our future food systems and guide them in articulating the underlying values and priorities, defining features, and patterns of behaviour that form the pillars of a new food system. Once the group generates this collaborative vision, they are prompted to bring themselves back to the present and identify glimpses of this future that exist in the present through the lens of new ideas and technologies that exist but are not yet dominant forces in our food system.

The themes uncovered from the Horizon Three discussion articulate a desired future for the Canadian food system co-created by the workshop participants. This future is defined by core values of a new food system that enable its resilience and food security in the form of increased availability and accessibility of food. By generating this vision for the future, the workshop participants are showcasing a future operating. Data from this section of the workshop informed the leverage points from which AI interventions could accelerate the transition between the status quo and the desired future.

Horizon Two

The Horizon Two section of the workshop defines the innovation space which lies within the transition between the Horizon One (status quo) and Horizon Three (desired future). The innovation space populated during the Horizon Two section can be seen as a roadmap towards the desired future. There are two distinct types of innovation actions within this space, H- and H+. H- actions incrementally improve the status quo while H+ actions disrupt the dominant paradigm and work to make the desired future a present reality. In the context of this research project, H- actions address the issues with Canadian food systems that were highlighted during the Horizon One discussion and incrementally improve the alignment of our food systems with circular principles. H+ actions seek to transform our food system into one co-envisioned by workshop participants during the Horizon Three section. Data from this section of the workshop informed the specific use cases for AI to act on the leverage points uncovered during the synthesis process, and identified areas for future research and action outside of the scope of this project which could enable transformative changes to our society and food systems, such as shifts in societal values and government policy interventions.

Section 3 - Literature Review

The following literature review expands on the problem space of this research project (cities, food systems and climate change), introduces the circular economy framework, and explores circularity within food systems. It also highlights some promising solutions aligning with the circular economy principles and artificial intelligence as an integrated tool to aid in an accelerated transition to circular food systems. Preliminary data suggests food systems are a major contributor to climate change, but also play a crucial role in addressing emissions and building resilience within cities. Data from this review will be synthesised with workshop data to identify leverage points for AI interventions to transition towards circular food systems and enable more resilience and security in food systems.

Problem Space: Cities & Climate Change

Globally, cities account for approximately 60% (United Nations, n.d.) of climate emissions, and as urbanization trends continue across the world, this figure will rise, unless corrective actions are taken. Food systems are one of Canada's nine critical infrastructure systems. Since cities are the most population-dense locations in the nation, cities put significant strain on food systems, and further drive waste and pollution issues already plaguing cities. The current, linear, food systems exacerbate the emissions and waste that cities produce, and by design, will continue to grow as urbanization continues. Food systems contribute significantly to greenhouse gas emissions, so as demand for food from cities rise, as do associated emissions.

Cities also play a critical role in Canada's national economy. A 2010 study published by Fan et al. from the City of Calgary's Corporate Economics team, found that the nation's six largest Census Metropolitan Areas (CMA's) account for approximately two-thirds of the economic growth, between 1998-2008, while cities overall (including the six largest) created 80% of growth. The same study emphasized that cities impact local and national economic development through three main channels: sharing, matching, and learning. Sharing includes benefits of variety for consumers in local markets. Matching refers to increased probability of quality matches in the labor force. And finally learning refers to the role cities play in knowledge generation through research and innovation centers, and the accumulation and diffusion of knowledge though large populations and knowledge institutions like universities. These channels provide a framework to understand how AI research and development, currently occurring in Vancouver, Edmonton, Toronto, and Montreal (CiFAR, n.d.), could enable economic development in these cities while developing future solutions to sustainable food production challenges. Cities with AI innovation hubs are well positioned, with their ability to disperse knowledge (learning channel) and draw upon local talent (matching channel), to harness AI to develop innovative products and services to create value through food system interventions that could enable progress towards a circular economy goals, such as the design of more sustainable food products for local consumers, the operation of local hydroponic food production facilities that minimize waste and pollution through shorter supply chains for consumers to enjoy a greater variety food products.

Although cities and their large populations demand the majority of food resources relative to rural areas, most food production occurs outside of urban areas. Therefore, urban food systems must be considered within the context of the broader national and global foods systems from which they draw resources. A study by Crippa et. al (2021), attempts to estimate the proportion (and breakdown) of greenhouse gas emissions that come from food systems. Their results found that food systems account for almost a third of emissions globally. This study estimated that Canadian food systems accounted for 30-40% of its overall emissions. This figure is further segmented into land-based (69%), energy (22%), industry (6%), and waste (3%). This showcases an opportunity for reducing emissions through AI interventions that reinforce the circular principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems. AI's capabilities in boosting operational efficiency through automation and predictive capabilities enabled by machine-learning algorithms can specifically address the energy use, waste, and industry segments of these greenhouse gas figures, if harnessed by industry stakeholders. The waste and pollution noted above drives the effects of climate change, which in turn threatens the resilience of food system through extreme weather events (such as heat waves, droughts, and hurricanes) that disrupt supply chains, and food security due to the loss of arable land from impacts like wildfires and flooding.

One of the primary objectives of this research project is to inform businesses and policy makers on how to enable more resilient and secure food systems. The Prairie Climate Centre investigated the role of food systems in building climate resilient cities and found that strong local food systems can increase resilience to supply shocks from international supply chains (Temmer, 2017) and enable cities to maintain their critical food infrastructure during times of crisis. This report highlighted the role that local food production plays in building this resilience, but also emphasized the importance of shorter and more localized supply chains, technologies such as hydroponics, aquaponics, and vertical farming (to reduce the demand for soil), and regulatory changes in zoning laws to enable more local agricultural activities within city limits. These factors provide examples of technologies that enable more resilience and food security and highlight the need to increase urban food production capabilities. By integrating these technologies with AI algorithms which can automate and optimize their operations to maximize production based on environmental conditions and local demand, the role these technologies play in building resilience and security are further reinforced, while progressing towards circular goals of minimizing waste and pollution in food systems. These technologies reduce waste and pollution by shortening supply chains, while AI can improve their operational efficiency through automation to further reduce potential waste.

Supply-chain fragility is a critical issue impacting the resilience of Canadian food systems and our food security and reinforces our linear systems by increasing the potential waste and pollution associate with food supplies. Chouinard and Hales (2019), through Defence Research and Development Canada prepared a fourth volume of a report on the National Critical Infrastructure Interdependency Model that focused on food systems. It provides an overview of the status quo of Canada's food infrastructure, its interdependence, and vulnerabilities. The report also draws upon case studies from other nations, namely Australia, to provide focus areas to improve the resiliency of Canada's food systems. Based on its exploration of Canada's food system and Australian case study analysis, it concludes that long and complex supply chains, and a "just in time" production model are key vulnerabilities and threats to resilience in the face of high probability threats such as extreme weather, pests and animal diseases, disruptions to other critical infrastructure like water or energy, and contamination of agricultural sector inputs such as water, fertilizer, and seed. The vulnerabilities outlined and recommendations for enabling resilience suggest that supply chains are a potential leverage point where AI interventions could improve the resilience and security of Canadian food systems. The three horizons workshop will further explore how AI could specifically impact supply chains to drive reductions in waste, shorter supply chains, and more resilience in the face of supply shocks.

Parfitt, Barthel, and Macnaughton (2010) attempted to quantify food waste within supply chains though an international literature review, in the hopes of understanding the depth of the food waste problem. Their analysis revealed developed nations see most waste in the post-consumption phase. Since this research project looks identify opportunities for Canada's food system to move towards circularity, it would be beneficial to focus AI projects and solutions towards minimizing waste after consumption or designing solutions to re-use food waste products to loop back into the system.

Exploring Solutions

Circular Economy

The circular economy is a concept popularized by the Ellen MacArthur Foundation, and sets out three simple concepts to guide the design of economies, and the systems that exist in them.

1. Design out waste
2. Maximize Re-use
3. Regenerate Natural Systems

For food systems, the circular concept can be applied to transition away from linear food production models, in which food moves in a single direction, and ends with waste at each stage. A circular framework could enable reductions in waste throughout the food journey through design-led innovations, emphasizing the regeneration of soil systems and ecosystems disrupted by current food systems, and by finding opportunities to reuse resources that go into food production, distribution, and consumption (Ellen MacArthur Foundation, n.d.). These focus areas represent possible inflection points where the strategic application of AI interventions generated during the Three Horizons workshop might accelerate the transition towards a circular food system in Canada.

The Ellen MacArthur Foundation (2019) also produced a report on cities and the circular economy for food. In it, they outline several case studies of cities initiating circular food projects, and their expected benefits (Table 1). These benefits fall under the following categories:

environmental, economic, and health.

City	Circular Project	Projected Benefits
Brussels, Belgium	Supporting development of locally sourced and regeneratively grown food	• $31M USD savings in health costs (economic and health benefit). • Healthier soils enhanced by organic alternatives to synthetic fertilizers leading to $11M USD saved by avoiding soil degradation (economic and environmental benefit). • Reducing GHG emissions by 42,000 tonnes (environmental benefit). •21 Million m3 water savings from healthier soils (environmental benefit).
Guelph, Canada	Using biosoils from wastewater treatment for regenerative farming	• Creation of new business models and revenue streams for businesses (economic benefit). • Recovery of $34,000 USD of nitrogen and phosphorus for organic fertilizer per year (economic benefit). • Addition of 1000 hectares of nutrient rich cropland from organic fertilizer (environmental benefit).
Porto, Portugal	Collaborating across municipalities to make the most of food	• Estimated $14M USD savings due to reduction in negative health impacts from food production and waste (economic and health benefit). • $92M USD of value from food no longer wasted (environmental and economic benefit)..
Sao Paulo, Brazil	Re-localizing food production while transitioning to regenerative practices for a more resilient, socially inclusive urban food system.	• $67M USD health cost savings due to reductions in pesticide exposure and air pollution (environmental, health, and economic benefit).. • Preventing $25M USD of soil degradation (environmental and economic benefit). • Avoiding 92,000 tonnes of GHG emissions (environmental benefit). • 46 million m3 of freshwater was saved (environmental benefit). • Diversification of both crops and revenue streams for farmers (economic and environmental benefit).

Table 1 – Examples of Circular Food Project & Benefits

(Ellen MacArthur Foundation, 2019)

The above projects demonstrate the complex and interconnected nature of moving towards a fully circular food system, while also showcasing the intersecting economic, environmental, and health benefits of doing so, even on a small scale. AI technologies could possibly aid in many of these efforts through data tracking capabilities, and its demonstrated ability to scale business operations.

The case study from Porto best exemplifies a use case for AI, since it addresses food waste, which is a sizable problem globally and represents an ideal problem-solution fit with AI. By collaborating across communities to ensure food was better distributed amongst the population, Porto was able to reduce food waste, and the associated negative health and environmental impacts from overproduction. The net reduction in food waste also translated to a direct economic benefit of $92M USD. The Porto project maps well onto resource optimization problems that AI is well-suited for, which indicates an opportunity for AI to be applied to similar projects to expand its scope and increase the associated benefits. For example, AI could track and process data from more collaborating communities to feed into the Porto project and automate distribution of food across these communities to further minimize waste. The Sao Paulo project, which sought to re-localize food production in a regenerative manner, could also benefit from AI. For example, AI could be integrated into non-soil farming infrastructure such as vertical farming units, to add more local production capabilities to Sao Paulo without increasing demands on soil.

Lavelli (2021) investigated opportunities and threats associated with circular supply chains and found that value creation opportunities exist in converting by-products of food into new products (p. 324). However, Lavelli cautions that these opportunities come with risks associated with contamination and loss of batch identification. Lavelli concludes by highlighting the need to integrate forecasting and optimization studies into the circular strategy to adequately manage these risks. Current of AI products are well suited to meet these needs since they can process and analyze immense datasets through algorithms that generate predictions and optimizations based on goals defined by coders – in this case minimizing contamination risk. Lavelli's concludes demonstrates an opportunity for an AI intervention to help accelerate the transition to circular supply chains for food systems through a problem-solution fit.

Sustainable Conceptual Frameworks

Although the circular economy framework has merit in its simplicity, versatility, and adoption among policymakers and businesses, it comes with some limitations, which should be considered in the context of expanding potential frameworks to guide businesses and policy-makers in implementing food system projects and policies in the future. Koppelmaki et al. (2021) offer some gaps in the circular economy concept, specific to the food system, and outlines challenges associated with its application. They share critiques of the concept, namely its vagueness and lack of clear definitions and attempt to address this by unpacking two main gaps. First, a failure to advance beyond nutrient cycling when applying systems perspectives to quantify circularity. Second, limited knowledge of the interconnectedness and spatial scales of biomass flows at a food systems level, which impacts the ability to make these flows more circular. The authors attempt to rectify these gaps by proposing a nested circularity concept to better connect and close nutrient, biomass, and energy cycles through many spatial scales. This concept will aid this research project in identifying key stakeholders and AI products that can support "closing the loop" and identifying connections at and between each distinct scale of biomass, nutrients, and energy. Considering the limitations of the circular framework, the Horizon Three section of the workshop should empower participants to refer to, but not necessarily attach themselves to a solely circular food framework for their Horizon Three vision. This flexibility should enable the researcher to better synthesize and capture emergent values, features, and priorities of participants from the Horizon Three discussion, that align with circular principles, but perhaps extend beyond it to enable resilience and food security within a Canadian context.

Hamam et al. (2021) provide a comprehensive review of circular economy models in agro-food systems. This review selected topics in business model and organization management, food loss and waste in supply chains, analytic tools for circular economies, stakeholder acceptance, and mitigation strategies and politics. Key findings include a need for integrated approaches to supply chain management and cooperation between stakeholders to minimize food waste, and acceptance by consumers of new food products utilizing previously wasted ingredients. The review also highlighted the opportunity for enterprises to deliver products and services that could leverage innovation and technology to improve efficiency and sustainability in the market by using the circular concept as a guide. These findings further support the business case (market opportunity) for AI products to optimize processes and business models within the agro-foods sector, as businesses, consumers, and governments transition towards a circular economy. AI is well suited to tackle the analytic challenges this review presents in terms of accounting for materials and waste flows within food systems and designing systems to maximize their lifetime. However, it also notes a need to break down barriers consumers may face in terms of trying new food products. AI technologies might also be leveraged to improve food safety assessments, risk management, and by providing data to enhance consumer confidence in these new products. A tangential example of AI applied to safety and risk management is the use of motion capture technologies and computer vision (a type of AI algorithm) to assess ergonomic risks in workplaces (VelocityEHS, 2022). The review by Hamam et al. also demonstrates the importance of consumers in the transition towards circular food systems, and emphasizes their role in accelerating the transition through the demand side of the market. An example of AI applied to system design can be seen through the work of Poteralski & Szczpanik (2016) who utilized bio-inspired AI algorithms to optimize mechanical systems based on selected parameters. Pena et al. (2021) also review 75 case studies of AI systems generating conceptual designs in architecture by utilizing specific methods such as evolutionary computation, neural networks, fractals, swarm intelligence, and cellular automata.

AI can provide many benefits for food producers, namely increases in operational efficiency. However, if these efficiency gains are within the context of unsustainable linear food production practices and business models, they only offer incremental improvements to the waste reduction of the status quo. Cambridge researchers Bocken, Short, Rana, and Evans (2014) proposed a series of sustainable business model archetypes to accelerate development of sustainable business models, both in research and practice. This categorization provides a more specific common language that could provide more clarity for AI researchers and practitioners looking to leverage technology to design circular business models. The archetypes are as follows: maximize material and energy efficiency, create value from waste, substitute with renewables and natural processes, deliver functionality rather than ownership, adopt a stewardship role, encourage sufficiency, re-purpose for society/environment, and develop scale-up solutions. Of these archetypes, scale-up solutions and maximization of material and energy efficiency is best suited for the application of AI. Thus, seeking opportunities to design circular businesses within current food systems that address these would help accelerate overall progress towards a circular food system. For example, small urban farming techniques that provides a modest amounts of food could be enhanced through scaling solutions that might enable them to feed larger communities more reliably.

Artificial Intelligence

A collaborative report on artificial intelligence and the circular economy developed by the Ellen MacArthur Foundation, Google, and McKinsey (2019) sought to showcase the transformative potential of AI transitions towards circular economies, the economic value that could be captured in this transition, and case studies of projects already occurring in a range of sectors, including food systems.

The report notes that AI's capacity to design out waste can transfer up to $127B USD of value to food systems per year by 2030. An example of AI products driving waste elimination in food systems includes the work of companies such as Wasteless that utilize AI to help retailers minimize food-related waste and estimates a boost in revenue for retailers and reductions in food waste amounting to a minimum of 20% increase in revenue (Wasteless, n.d.). It does this by integrating AI into software that provides decision-support systems to retailers with data-driven insights that lead to increased sales revenue. It also boosts profits by providing real time sales data and consumer behaviour insights that lead to reductions in wasted (unsold) supply and returns. Wasteless also drives revenue while minimize waste by harnessing a machine learning algorithm providing dynamic pricing based on the freshness of foods, and the likelihood of sales at a given price point. This demonstrates the feasibility and market opportunity for AI products that address food waste. Food waste accounts for approximately $21B of losses annually (City of Toronto, n.d.), which represents the market opportunity in Canada.

Finally, the report notes the following categorization of AI applications, based on Google's extensive use and research on artificial intelligence, both internally and in other business applications. These archetypal AI applications will be shared as a resource for workshop participants in ideating food system opportunities and challenges with AI applications:

- Data collection & engineering
- Algorithm development & refinement
- Decisions based on algorithm output
    - Pattern recognition
    - Prediction
    - Optimization & planning
    - Integrated solutions with robots

The report also noted several promising case studies that demonstrated the problem-solution fit between AI and circular food systems. The overarching categories of interventions include growing food regeneratively and utilizing its by-products more effectively, aiding in locally and regenerative sourced food, designing out food waste, designing and marketing healthier food products, and valorization of food waste and by-products. Some specific examples are as follows:

1. CiBO Technologies using analytics and statistical modeling within AI products for agricultural ecosystem simulations under different conditions. CiBO also leverages drones, remote sensors, satellites, and smart farm equipment for real-time data collection and reporting to aid farmers in decision-making.
2. PlantVillage is an R&D wing of Penn State University that has developed an AI assistant (Nuru), that enables expert-level crop disease diagnosis using computer vision, anomaly detection and forecasting based on sensor data, and automated responses to questions from farmers by leveraging natural language processes algorithms to enable human language comprehension (PlantVilliage, n.d).
3. Harvest CROO Robotics is a company leveraging AI to analyze images of strawberries to determine suitability for harvest, and reduce the probability of food waste, enable more accurate yield forecasts, and as a result increase supply chain efficiency. This is an example of computer vision (a type of AI application) being combined with machine learning algorithms (another type of AI application) to enable predictive capabilities of the AI system to improve the efficiency of food systems through interventions that impact supply chains and waste.
4. TOMRA is a company employing technologies to improve the sorting, separation, and valorization of food. Sensors autonomously detect and analyze the suitability of food for direct-consumer sales or use in other food products, to minimize overall waste.
5. NotCo is a company that utilizes machine learning algorithms to develop food formulas for new plant-based foods by detecting molecular-level patterns analyzing flavor molecules. Technologies like these can reduce the level of meat and dairy consumption and demand, which will make an impact on GHG emissions.

6. Wasteless is a company that helps retailers waste less expired foods by providing AI-aided tracking and dynamic pricing to enable products to be sold before expiry dates. This is an example of AI reducing waste by addressing supply chain waste. Providing a financial incentive for consumers to purchase food before it expires prevents it from being wasted while securing revenue for retailers.
7. Google's own X lab analyzes its own food program to find new uses for unused foods and provide potential recipes based on leftover products. This is an example of AI designing waste out of the system and keeping products and materials in use. It accomplishes this by utilizing computer vision to process images of unused foods, and deep learning algorithms to suggest new recipes based on data on existing recipes.

The case studies summarized above, showcase the current innovation space with respect to AI being harnessed for projects focused on outcomes that would align with circular principles. Canadian businesses operating in technology space could capture value by accelerating research and development in the above areas, while policymakers and incubators could focus investment efforts on projects and businesses develop solutions leading to circular outcomes, as noted above. The examples above indicate the presence of a market in the circular food space, and adds evidence for economic value through investments from businesses and policy-makers.

Building on the archetypes outlined above, a specific use case of AI in creating value from waste exists in the food supply chain. Belaud et al. (2019) provide an approach to apply big data for sustainability management using by-products of the supply chain. This approach is useful in that supply chain waste has been noted by several researchers as a key source of waste leakage that must be closed in the path to circularity. This research aligns with the many case studies outlined that leverage AI to make better use of food by-products and loop them back into the system.

Section 4 - Discussion

The Emergent System

The literature review highlighted the role cities play in driving climate change (through emissions), and the role our food systems play in driving waste, pollution, and threats to food security. Data generated during the Three Horizons workshop built on the literature review by uncovering leverage points that reduce the resilience of food system infrastructure, issues plaguing our current food systems, and values systems that drive motivations and incentives of key food system stakeholders. A synthesis of insights from the Three Horizons Workshop and literature review revealed an emergent system in which Canada's urban food systems exists. This broader, global system is highly interconnected and has a major impact on food security in urban centres.

Consumers, governments, and the food industry are three major stakeholders that drive incentives, actions, and outcomes which impact the Canadian food system. A capitalist value system underpins and influences the incentives and motivations of all three of these stakeholders by shaping their priorities. For consumers these priorities include reducing food costs, increasing their food options, and acquiring food with greater degrees of convenience, quality, and satisfaction. For major stakeholders in the food industry (producers and retailers) the central priority is to remain profitable and increase their market share in an increasingly competitive and interconnected global market. Workshop participants collaboratively identified producers accomplishing this by focusing on reducing production costs by accessing cheaper labour sources, increasing production capacity by buying more land and further industrializing farming practices, maximizing crop yields through the use of herbicides and pesticides, increasing sales margins by selecting crops based on profit potential, and exploring new markets and revenue streams to increase their market share by developing cheap (and addictive) processed foods and securing IP rights on seeds. Food retailers prioritize increased sales, marketing high-margin food products with high demand, and reducing their operational costs. Workshop participants noted that consumer behaviours influence actions of retailers who maximize the food options available and minimize the price to consumers by expanding their supply chain internationally. Meanwhile, governments must balance the needs of their domestic food industry and consumers. The capitalist value system provides governments with incentives to maximize their own revenue through taxes, which is collected through increased food industry revenues, and more jobs within the food industry. In theory, by maximizing their own revenue, they have more resources with which to address consumer needs (food safety and competition) and environmental issues. According to Agri-Foods SMEs from the workshop, in reality, the emergent, profit-centric global system disproportionately increases the influence of large multinationals within the food industry, who can impact policy through the use of lobbying groups while minimizing the voice of smaller players, the environment, and sometimes consumers.

The actions of the government, consumers, and food industry are driving a negative reinforcing feedback loop with the environment, leading to increased carbon emissions, soil degradation, and vulnerability to the impacts of climate change. Agri-Foods SMEs from the workshop noted that the food industry, driven by consumer demands and a profit motive, relies heavily on monocultures (the use of a single crop for operational efficiency), herbicides, and cheap labour. The selection of monoculture crops is also driven by those that will reap the highest margins and most sales on the market. The use of monoculture crops contributes to soil erosion and reduces the long-term viability of the land. According to the Agri-foods SME from the workshop, most small holder farmers are forced to rent their land from large multinationals, who dictate the aforementioned farming practices. A large and complex international supply chain enables access to global markets, and the demands of international consumers. In this global market, large multinational corporations can reap the rewards of economies of scale, and in doing so, capture the majority of the market. These monopolistic entities are a driving force in the international food system, and heavily influences other food system stakeholders. They impact the behaviours of smaller farmers by through rental agreements on land and mandating crop selection and farming practices that will reinforce their economies of scale (such as herbicides, pesticides, high-yield crop selection, and monocultures). As larger companies capture a broader market share, they can influence consumer efforts through marketing efforts that can boost the sales of high-margin food products, which are often highly addicting, low in nutritional content, and cheap. Workshop participants highlighted that these companies are also able to translate sizable profits, international presence, and large labour forces, into government influence by utilizing lobbying groups to represent their interest in the development of food policy. These leads to government food policies that often benefit the largest food industry actors that the detriment of other stakeholders such as consumers. Workshop participants specifically highlighted a lack of transparency around labelling regulations as an example of the government policy benefiting large food producers to the detriment of consumers. Consumer demands also incentivize and reinforce food industry behaviours due to their preference for lower costs, year-round selection of any food products, convenience, and consistently high taste and aesthetic quality. Workshop participants acknowledged the role consumer purchasing decisions, and the social aspect of food (sharing only the best you can offer), plays in producers and retailers working to enable a long and s=complex supply chain that can almost any food items to Canadian consumers year-round, despite natural seasonality. According to several workshop groups consumer aversion to produce with minor imperfections also drives much of the waste in the supply chain.

The impacts of the emergent system described in this section are threatening food security due to the centralization of food production, environmental degradation, elevated supply-chain risks, increasing socioeconomic inequities, waste, and cascading impacts of climate change.

Centralization emerges due to actions of food producers and consumers that incentivize large-scale farming operations that benefit from economies of scale. These actions, also leads to sizable amounts of waste and pollution from the food supply chain. Environmental degradation is driven by the practices of the food industry directly leading to soil erosion (monocultures, pesticides, herbicides) and significant carbon emissions that drive climate change. As the effects of climate change continue to increase in magnitude and frequency, this depleted environmental condition leads to a loss of arable land and leaves the food system vulnerable to elevated risks due to direct climate events (extreme weather, floods, droughts, wildfires). This risk is exacerbated through a long-and complex international supply chain that is prone to global geopolitical and climate events that impact food production and distribution, such as wars, diseases, and natural disasters. This fragile supply chain threatens food security in Canadian cities through its impacts on accessibility in urban areas and affordability for lower-income individuals. Urban centres do not possess the local production capacity to meet consumer demand, and supply shortages leads to elevated food prices, which reduces affordability. This has the greatest impact on lower-impact individuals, and less-so on high earners, since the food inflation eats away at a small proportion of their overall income. Furthermore, lower-income individuals are often priced out of more nutritious, healthier, sustainably, and ethically sources food options (especially during supply shortages) and are constrained to cheaper options. This places a “health tax” based on socioeconomic status due to the negative health impacts associated with cheaper, highly-processed foods.

System Drivers

The emergent system, which leads to outcomes threatening food system resilience and security, are driven by capitalist values and climate change. Capitalist values drive the motivations and incentives of human components of the system (food industry, consumers, governments), while climate change drives effects that impact the environment from which human components extract resources and depend on for survival.

Capitalist Values

Workshop participants identified capitalist values as forming foundational values of our food system and influencing the incentives and actions of the food producers, retailers, consumers, and the government.

An emergent theme during the workshop discussion was that that maximizing profit was a greater driver in decisions within the food industry than maximizing the amount of people fed, despite adequate supply to do so. Participants shared supporting evidence of these claims, such as the fact that Canada is a net exporter of food, yet several people experience hunger domestically. Participants who were subject matter experts (SMEs) within the Agri-foods sector also shared that a focus on maximizing production and sales, leads to a lot of viable food being discarded because it does not look "sellable." Other profit-centric priorities shared include pressure to reduce operating costs, filing for intellectual property rights over seeds and restricting their use, and selection of crops based on potential revenue.

The workshop discussion also highlighted the role these capitalist values play in influencing consumer demands purchasing behaviours. Several participants noted, based on their observation of their own behaviours and that of their community, that most Canadians have come to expect an abundance of food options year-round, seek to minimize their food costs by opting for the best price possible, pass up on foods with aesthetic defects, and opt for food choices that enable them to maintain their social status when sharing it with friends and family. These consumer demands (wide selection, low prices, and high quality), influences the behaviours of producers and retailers to meet their demands in a competitive global market.

Climate Change

According to the sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC) (2022), the effects of climate change include the Increasing frequency and magnitude of weather extremes on land and ocean, heavy precipitation events, and drought and fire weather (p.9). These effects are driving impacts on natural systems through to changes in ecosystems, reductions in biodiversity, and timing of natural processes (p.10). These effects, in aggregate, impact human systems in three broad categories that are further segmented as follows:

- Water scarcity and food production
    - Increasing water scarcity
    - Threats to agricultural, animal, and fisheries production
- Health and wellbeing
    - Prevalence of infectious diseases
    - Pervasive heat and malnutrition issues
    - Mental health issues
    - Displacement
- Cities, settlements, and infrastructure
    - Inland and coastal flooding associated damages
    - Damage to infrastructure
    - Damage to economic sectors

(IPCC, 2022, p.10)

The effects above, have direct implications for food systems, which will be discussed in the context of the environment, in the following section. Since food systems are also a driver of the effects of climate change, due to its greenhouse gas emissions, these effects also have cascading impacts that threaten food system resilience and security. These cascading impacts will be discussed in the section, “Outcomes of the Emergent System” in the context of several outcomes that are threatening food system resilience and security in Canada.

Components of this emergent system include the food industry, consumers, governments, and the environment. Capitalistic values drive the incentives and priorities that lead to actions from the food industry, consumers, and governments. The effects of climate change drives direct impacts on food systems worldwide, which in turn creates added pressure on the food industry to meet the demands of consumers. This section will explore how capitalist values influence the actions of the system components, the impacts of these actions, and the impacts of climate change on food systems. The aggregate of these impacts leads to specific outcomes that threaten food security and the resilience of urban food systems, which will be further explored in the next section (Outcomes).

Food Industry

As noted in the previous section, capitalist values manifest as profit-driven motivations that incentivize actions and behaviours that reduce costs, maximize revenues, and increase market share within in the food industry for producers and retailers. Food producers accomplish this through industrial farming practices that maximize production, profit-driven crop selection, minimizing labour costs, maximizing the selling window for foods, and securing new revenue streams. Profit motives incentivize retailers to turn away cosmetically imperfect foods, utilize just-in-time deliveries (JIT) from producers, and expand their supply chain to meet consumer expectations.

Producers

Industrialization of Farming

A workshop participant who is an SME in the Agri-Foods sector noted that the industry has embraced the industrialization of farming practices to maximize their production capabilities and potential revenue. For larger Agri-Foods corporations, such as Monsanto or Cargill, these industrialization activities lead to greater profits and market capitalization from the economies of scale they benefit from. Some specific actions that reinforce this industrialization which workshop SMEs in Agri-foods and biotechnology identified include the use of monocultures, application of herbicides and pesticides, and the use of industrial facilities and equipment to enable mass scale farming. Monocultures are the use of a single crop to enable more efficiency and profits for producers. Herbicides and pesticides enable producers to maintain quality and reduce losses from weeds and pests. Industrial farming facilities and equipment enable reductions in labour costs in large scale farming activities.

The use of pesticides and herbicides have negative impacts on ecosystems, public health, and some crops. Agriculture and Life Sciences researcher David Pimentel (2005), from Cornell University studied the environmental and economic costs associated with pesticide use in the US and found that it contributed to $1.1 billion in public healthcare costs, $1.5 billion due to pesticide resistance in pests, $1.4 billion due to crop losses caused by pesticide use, $2.2 billion in wildlife (bird) losses, and $2.0 billion in groundwater contamination.

The prevalence of monocultures are problematic because it leads to soil erosion and an increased use of pesticides (Makowski, 2019). The Agri-foods workshop SME highlighted those issues can be mitigated by rotating crops and growing a more diverse range of crops.

The equipment, facilities, and fertilizer used in industrial farming practices contribute to sizable amounts of energy use and pollution. Agriculture and Agri-Foods Canada (2022) released a discussion paper on reducing emissions from fertilizer use, and noted that 10% of Canada's greenhouse gas emissions were from the agriculture industry. The paper also highlights that the major sources of these emissions are on-farm fuel use, crop production, and enteric fermentation (gases released from animals).

Profit-Driven Crop Selection

The Agri-foods SME also noted that profit-driven incentives lead to crop selection based on global market values and potential sales. Profit-driven crop selection also sets the prioritization of which crop will be part of monocultures. Since it is a global market that sets demand, producers are incentivized to prioritize the needs of this global market since this will significantly expand their revenues and potential profits. Workshop participants also highlighted that as producers grow their market share, they benefit from economies of scale from the large-scale farming operations needed to provide the requisite supply, which further increases their profits.

Minimizing Labour Costs

The profit motive for producers also leads to a push to minimize labour costs associated with production. Workshop SMEs in biotechnology and Agri-foods also emphasized how pressure to maximize profit disproportionately impacts labourers working in the industry. It was noted that producers regularly overwork domestic workers, rely on migrant workers for lower cost labour, and often outsource to other nations that can provide lower-cost food production. Outsourcing food production to reduce labour costs reinforces the long supply chain for our food systems and associated emissions that come with transporting foods a long distance.

Maximizing Selling Windows

Agri-food SME also noted that demands to maximize the selling window of food also leads to the use of preservation techniques like food packaging and refrigeration. They noted that food packaging contributes to the plastic waste accumulated from the industry and refrigeration techniques are energy intensive and drive emissions. However, preserving the selling window of foods also reduces the amount of food waste lost to spoiled food, so there are environmental benefits to these techniques, despite the profit motives behind them.

Expanding Revenue Streams

The workshop SMEs in Agri-foods and biotechnology also emphasized that the drive to increase profits leads to larger corporations to expand their revenue streams by investing in R&D and legal resources to develop IP on seeds, leasing out large portions of the land they own to smaller farmers, and developing new ultra-processed food products with high margins and sales potential.

Workshop SMEs noted that developing IP on seeds and leasing out land to smaller farmers enable corporations to secure revenue through a portion of crop sales over several generations of seeds, while externalizing operational costs to leasing farmers and maintaining equity on large portions of land. By leasing out land, they are also able to dictate farming practices that will drive production and sales revenue, such as the use of monocultures that they select, and herbicide and pesticide use.

Participants also highlighted that new food products that are ultra-processed also drive sales for producers. Ultra-processed foods dominate food supply in high-income nations like Canada, according to a health report published through Statistics Canada (Polsky et al., 2020). The same report noted that these foods are cheap to produce and contain additives (such as sugar) that make them low-cost sources of energy, but low in nutritional content. Public health researcher Jessica O'Neill from the University of Buffalo emphasizes that ultra-processed foods are engineered to induce addictive behaviours, and that the low production costs associated with these foods, and high sales (due to the addictive qualities), drive profits for producers (O'Neill, 2019). According to a synthesis review published in the International Journal of Health Policy Management, consumption of ultra-processed foods are associated with higher risks of non-communicable diseases in the public, and advocates for a public health response driven by a global network of individuals and government leadership (Moodie, et al., 2021).

Retailers

Rejecting Cosmetic Defects

Multiple workshop participants shared a lot of waste is driven by retailers and consumers rejecting cosmetically imperfect foods. Retailers are incentivized to do this as these foods have a lower probability of selling prior to their selling window closing (going bad). According to a case study report from the University of British Columbia, insistence on cosmetically perfect produce leads to a loss of 40-50% of production losses globally. The same report highlighted those industrialized nations like Canada and the US absorb approximately $680 Billion USD of food waste throughout the supply chain annually (Nance et al., n.d.). Although retailers are a leverage point that facilitates much of this waste, this issue is driven by consumer demand, and leads to producers overproducing to ensure enough "perfect" foods are sold.

Just-In-Time Deliveries (JIT)

JIT deliveries minimizes inventory and improves production efficiency (Banton, 2022), so it could helps to reduce overall food waste and drive more profits for retailers. The Agri-food SME also shared that just-in-time (JIT) delivery was a common behaviour among producers & retailers because JIT allows producers to enable retailers to maximize their selling window. However, they also noted that since it also leads to increased carbon emissions from food distribution due to more frequent food deliveries. In the literature review, Chouinard and Hales (2019), highlighted JIT deliveries as one of the main vulnerabilities and threats to resilience in Canada's food infrastructure.

Expanding Supply Chain

Workshop SMEs in Agri-foods and critical infrastructure planning noted that an expanded supply-chain, driven by the consumer demands for a wide selection of foods at all times of the year for the lowest possible price, motivates retailers to source food from international suppliers that can provide out-of-season foods and competitive pricing. According to the critical infrastructure SME, the length and interconnectivity of the food supply chain poses a significant risk to Canada's food security.

Consumers

Capitalist values influence consumers to accumulate wealth and status in society. Reducing one's costs and having access to high quality items are two ways increasing this wealth and status.

In the context of food decisions, these motivations incentivize consumers to seek out the lowest prices, a wide selection of foods year-round, high quality (taste and cosmetic), and to ensure they have a surplus of food available for themselves, their families, and guests.

Workshop participants also highlighted the central role food plays in one's identity, and the social role of food in Canada. One participant remarked "there is social pressure to have more than enough food and put your best food out there when you invite people over."

Other workshop participants identified consumer demands for out-of-season foods as a major driver of the long supply chains that retailers and producers utilize to meet consumer needs. A participant also questions "do we really need mangos year-round? Would people still buy them if they knew the costs associated with having access to those mangos in the supermarket year-round?" This comment dovetailed into conversation about the lack of transparency in food system and the role government could play in addressing this issue.

These consumer demands for low prices incentivizes producers and retailers to lower their operating costs through industrial farming practices and expanding their supply chain globally to find the lowest cost suppliers. The demands for a wide selection of foods, even out-of-season, also reinforces the use of an international supply chain to find out of season food that can be delivered to consumers year-round. This supply chain can also provide foods that are not normally grown in Canada. Consumer also pass on purchasing foods with cosmetic defects, so producers and retailers also reject them, and over-produce crops to ensure that enough cosmetically perfect foods are available to consumers. Finally, consumers routinely over-purchase foods to ensure they have more than enough available and end up discarding them. As noted by Parfitt, Barthel, and Macnaughton (2010) in the literature review, post-consumption waste accounts for most of the food waste in developed nations. This means, consumers play a major role in driving the prevalence of long supply chains, industrialized farming, and waste in food systems either directly or through their purchasing habits.

Government

Capitalist values motivate governments to grow their yearly revenues (primarily from taxes) to fund their activities and programs. This creates incentives to support industries, lower public expenditures by protecting public health and security, and increase trade. As noted in the literature review, cities are the source of most economic activity and population in Canada, so they represent a major leverage point in advancing motives to support economies and protect public health and security.

Workshop SMEs in Agri-Foods commented that governments play a role in the lack of transparency in food systems and can improve this with better regulations. The specific example discussed was how food lobbies influence labelling regulations to be more favourable to industry stakeholders, which is sometimes detrimental to consumers. A related example was how there is a lack of transparency on exactly how much of an environmental impact our food purchases have through their sourcing, transportation, and packaging. This discussion led to a exploration of possible future interventions to fill the knowledge gap consumers have about their food choices, and will be explored further in the “Solutions” section of this report. Workshop participants expressed a sentiment that governments currently do not do enough to protect the interests of public health and the environment, and that the lack of transparency in foods systems are a feature of lobbying groups having influence to boost industry profits and international trade. Canada is major exporter of agricultural products, so there is an economic incentive to maintain our role in international food trade, however, as participants expressed, this comes at the cost of reinforcing the emergent system that is producing outcomes that are harming the environment and threatening public health and food security. These environmental impacts and systemic outcomes will be discussed further in the next sections, “Environment,” and “Outcomes of the Emergent System.”

Environment

The environment is the source of all natural resources which flow into food system. Workshop participants highlighted the extractive nature of the profit-driven food industry, and how it reduces the amount of natural resources available for future generations through actions such as monocultures. However, climate change is another driver that is impacting food systems and threatening global food security as a result. It is important to note, that the emergent system also drives the effects of climate change, so as natural resources are depleted due to climate change, the pressure to produce further increases.

Impacts of Climate Change on Food Systems

The effects of climate change are threatening food security due to its impacts on our interconnected global food system. The International Food Policy Research Institute (IFPRI) released a report on climate change & food systems and emphasized that "rising temperatures, changing precipitation patterns, and extreme weather events, among other effects, are already reducing agricultural yields and disrupting food supply chains. By 2050, climate change is expected to put millions of people at risk of huger, malnutrition, and poverty" (IFPRI, 2022, p.6). Considering the profit-driven motivations of the current food industry, reductions in agricultural yields and disrupted food supply chains will increase demands from consumers and further incentivize the profit-driven actions of the food industry expanded on above.

The Agri-foods SME also noted that climate change will have impact Canadian food systems differently than much of the world in that the warming will result in more arable land, especially in the North. So, this provides an opportunity to expand agricultural operations in a sustainable manner and address economic and environmental interests at the same time.

Outcomes of the Emergent System

The emergent system driven by capitalist values and climate change consists of impacts caused by the food industry, consumers, governments, and climate change. These impacts are driving outcomes which reduce the resilience of urban food systems and ultimately threatens Canada's food security. Those outcomes are also leverage points that can be reversed for a more resilient and secure future. The following section will summarize workshop discussions that explored the relationship between impacts of the status quo, outcomes that threaten food system resilience and security, and AI interventions that could address could reverse those outcomes.

Centralized Food Production

A theme that emerged from workshop discourse surrounding the macro effects of the impacts discussed in the previous section was that food production is centralized to a few corporations that dominate market share while operations are centralized to a few countries where large-scale operations, and practices like monocultures, drive overproduction (beyond the needs of the producing country) to satisfy global demand. An Agri-foods SME commented that "growing wheat can make you a lot of money, but it does not address food security in Canada." Internationally, countries overproduce crops that are best suited to their climate to satisfy demands in nations like Canada, where certain crops, like mangos, cannot grow naturally or are out of season. Another theme from the conversation about centralization was how it reduces the food sovereignty of communities and elevates food security risk due to the long and interconnected supply chains required to transport foods long distance.

Some of the specific drivers of this centralization effect that participants discussed include the practice of large corporations renting out land and dictating farming practices, intellectual property being placed on seeds (and those seeds being forced on renting farmers), and the economies of scale that industrialized practices enable (thus reinforcing a success to the successful systems loop where the largest corporations reap the largest rewards). Profit motives to grow "cash crops" and terms of land rental agreements push farmers to grow monocultures, which further drives centralization of food production to certain regions, to the detriment of the soil health and long-term land viability.

A theme that emerged from workshop discussions was the role AI could play in reinforcing localism and enabling a more decentralized food production network. Workshop SMEs in AI and Agri-foods collaborated with the rest of the group to generate a grounded vision of community-owned local food production networks, which harness the predictive capabilities of AI to anticipate supply chain issues and scale local production capabilities with automated hydroponic, aquaponic, and vertical farming systems.

Environmental Degradation

Another theme that emerged from the workshop was the acknowledgement that the effects of climate change and actions of an industrialized food industry (monocultures, pesticide & herbicide use, overproduction, and high energy use), degrade soil conditions and threaten the long-term viability of land for agriculture. This reduces the amount of arable land for Canadian farmers, and therefore our ability to produce food products. Agri-foods and AI SMEs shared that AI technologies exist which can provide insights for farmers to select crops that will improve long-term soil health, reduce their carbon footprint, and address food insecurity. These interventions actively regenerate natural systems and address food security at the same time. However, they also noted that technological adoption remains an issue among many large-scale farmers, and this must be overcome to reduce the widespread environmental degradation that results from industrial farming practices.

Interconnected & Fragile Supply Chains

A highly interconnected and fragile supply chain is an outcome of suppliers and producers expanding their supply chain to meet consumer demands of low prices and out-of-season selection year-round, and governments encouraging international trade (especially as a net exporter). A critical infrastructure SME emphasized that this interconnectedness is a threat to food systems and ultimately food security. This sentiment is shared by Chouinard and Hales (2019) in the literature review, who noted that long and complex supply chains, and a “just in time” production model were highlighted as key vulnerabilities and threats to resilience in the face of high probability threats such as extreme weather, pests and animal diseases, disruptions to other critical infrastructure like water or energy, and contamination of agricultural sector inputs such as water, fertilizer, and seeds.

Workshop participants who were SMEs in artificial intelligence noted that AI could address the fragility of supply chains through interventions that feed supply chain data into AI algorithms that utilize machine learning to predict supply shortages based on historical data and environmental conditions. However, the fragility of supply chains exists in the context of a global food where insufficient local production occurs in Canadian cities, so scaling up local production remains a challenge that must be addressed.

Waste

Linear food systems lead to more waste, producers are not incentivized to care about food waste, post-consumption waste in developed nations.

As the exploration on the emergent system showcased, waste is a major feature of food industry and consumer actions, primarily driven be capitalistic values that encourage excess. Producers, retailers, and consumers routinely discard viable food for cosmetic defects, and as noted by Parfitt, Barthel, and Macnaughton (2010), post-consumption waste accounts for the majority of food waste in developed nations like Canada. However, waste also exists within the international supply chain due to pests and insufficient cooling capabilities during their journeys. This waste is an indication of the inefficiency of food production and distribution, and threatens food security directly, since food is not reaching people, and indirectly due to the energy inputs (and associated emissions) that go into producing food that is ultimately discarded.

Workshop participants who were artificial intelligence SMEs shared that integrated AI systems using computer vision algorithms, remote sensors, and training data based on ripe food could predict when food will expire. Circular design SMEs ideated that the automation capabilities of AI could automatically sort and utilize food waste in other parts of the food system, such as food waste, to close the loop and enable circularity. This combination of AI and circular principles would help address food waste due to spoilage. AI SME's also noted that AI products could utilize predictive capabilities to anticipate supply chain needs, and provide insights to optimize production and reduce waste.

Premiums on Ethically and Sustainably Produced Food

As discussed in the emergent system section, profit motives incentivize producers to cut costs through unsustainable farming practices, minimizing labour costs, and by developing ultra-processed foods that have addictive qualities (and negative associated health outcomes). The current global market, and economies of scale benefit larger profitable producers and poses difficulty for ethical and sustainable food producers to capture market share and benefit from economies of scale to offer lower prices. Workshop participants emphasized that this reinforces inequities in society by pricing out lower-income individuals and places a "health tax" on them due to limited access (due to unaffordability) to more nutritious foods. The cost-effective options for these individuals are often the ultra-processed foods which drive negative health outcomes on individual and societal levels. The affordability challenges that these individuals face are a threaten their food security through affordability challenges that are further exacerbated during supply chain shocks. The threats associated with interconnectivity, discussed above, disproportionately expose individuals with lower levels of wealth.

Climate Change - Cascading Impacts

As our food systems continue their role as a driver of climate change, as do the cascading impacts of climate change, which in turn impact food systems. These include violence, disease, tensions due to growing populations and unsustainable and unethical practices.

Violence was explored during the workshop through the context of increased conflict due to a lack of availability and food production in some parts of the world, while geopolitical tensions, such as the war in Ukraine, adds strain to current food production. This adds pressure for more production and increases the potential for conflict in areas already battling with food scarcity. The geopolitical impacts for these conflicts could threaten Canada's food security due to the interconnectedness explored above.

As climate change increases the prevalence of famine, the spread of disease also increases. The interconnected nature of the food system comes into play here as well. As disease impacts plants, livestock, and humans, it further reduces availability and access to food products. A critical infrastructure SME also shared that a wave of swine flu in Africa is currently being monitored as a threat that could impact Canadian pork production, and potentially wipe out all pigs if the strain reaches Canada. This information led to a discourse of the COVID-19 pandemic as an example of how a human illness also adds strain and pressure to workers in food processing and production plants, which affects production and distribution of food.

As the shocks to the system impact production, as does the pressure to produce from increasing demand, driven by the market, and a growing global population. This further exacerbates the impacts and outcomes of the current food systems.

AI & critical infrastructure SMEs noted that AI that can predict and provide disease and extreme weather warnings could help mitigate against some of the cascading impacts of climate change and improve the resilience of current food systems.

Leveraging AI and Circular Economy Principles for Resilient & Secure Food Systems

The following section will explore how AI applications can enable a circular, resilient, and secure food systems. The circular economy framework directly addresses the environmental degradation and waste that are threatening resilience and security, through actions that design out waste and pollution, regenerate natural systems, and keep products and materials in use. AI interventions outside of a circular framework, can address the issues of centralization, interconnected and fragile supply chains, premiums on ethically and sustainably produced foods, and the cascading impacts of climate change to enable resilience and long-term food security.

AI for Circular Food Systems

As noted in the literature review, according to the Ellen MacArthur Foundation a circular framework would enable reductions in waste throughout the food journey through design-led innovations, emphasizing the regeneration of soil systems and ecosystems disrupted by current food systems, and by finding opportunities to reuse resources that go into food production, distribution, and consumption (Ellen MacArthur Foundation, 2019). The following sections will discuss current AI applications that address these focus areas, and potential AI interventions that workshop participants generated during the Three Horizons exercise that could support these areas.

Waste reductions through design-led innovations

A key theme in the workshop discussion on food system innovations to reduce waste involved AI accelerating research and development for new (more sustainable) food products and reducing waste by enabling more efficient food production systems.

The possible role of AI in food research is outlined by Tagkopoulos et al. (2022) from the University of California, Davis. They propose an AI institute for next generation food systems (AIFS) to accelerate research to transform food systems using AI to improve yield, quality, nutritional content, optimizing resource use, improving safety, and minimizing waste. They also note the following specific applications of AI to drive the outcomes highlighted above:

- Molecular Breeding
- Agricultural Production
- Food Processing and Distribution
- Nutrition

Molecular breeding extends being the capability to grow lab grown meat and dairy but also enables high-yield and quality vegetables, fruits, and nuts (Tagkopoulos et al, 2022, p.3). However, as Tagkopoulos' team highlights (p.3), AI can also address low-connectivity issues from typically remote areas where agricultural production occurs, by providing more memory and energy efficient hardware for better performing internet connections.

Workshop participants emphasized the role sustainable food science innovations such as lab grown meat and dairy, 3D printed foods, and dehydrated food could play in reducing waste and pollution associated with the food industry. AI can play a role in accelerating research and development for all of these applications by assisting research scientists in these fields. AI has already been playing a role in accelerating scientific research. A notable example is Google's AI conducting microchip designs faster than their own chip designers (Goldie & Mirhoseini, 2020; Thompson & Baker, 2021). Lab grown meat and dairy is a growing technology that can reduce the carbon emissions associated with the meat and dairy industry, which is beginning to see AI accelerate research associated development (Penarredonda, 2017). 3D printed foods, which are only in an experimental phase, offer potential to further decentralize the food supply chain, if it reaches maturity. Although this technology is promising, questions remain over food safety, and the environmental impact of materials used in the printing process. If sustainably sourced food materials and renewable energy sources can be used in the process, this offers potential to create new food products that people can enjoy in their homes, without the need for packaging or distribution (Rogers & Srivastava, 2021). It moves us closer to a circular food system by minimizing the pollution and waste that comes from food packaging operations (both materials and energy) and distribution. Investments in research from AI hubs in Canada focused on developing and scaling the design and production of 3D printed, sustainably sourced foods can move this promising technology from a glimpse of a future solution into a present reality. Generative AI designs are already in use in other fields such as architecture to develop new design solutions (Baldwin, 2020).

Workshop SMEs in biotechnology, urban agriculture, and Agri-foods noted that vertical farming and hydroponics both enable more food growing spaces to be created, while limiting the use of soil and land. SMEs in AI discussed how both technologies can be enhanced by AI through integration into intelligent systems that provide monitoring and precise management of conditions to maximize yield and minimize crop waste.

A workshop SME in critical infrastructure discussed a proposed geothermal-powered vertical farming operation in Hinton, AB as an example of food system innovations that draw upon renewable resources to enable les waste and pollution. By drilling deep vertical farming spaces, less land area is required, and by harnessing geothermal power from the land itself, reliance on fossil fuels are minimized in food produced from these operations (Lachacz, 2022). Furthermore, local knowledge of drilling operations typically applied to the fossil fuel industry are harnessed to develop this innovative solution. This is critical, as it enables the local economy to continue thriving as a shift from fossil fuels occurs.

Emphasizing the regeneration of soil systems and ecosystems

An SME with a background in both AI and agri-foods commented that "today AI exists that predict and provide mitigating measures for air, water, soil, and nitrogen amounts, while suggesting what crops you should be planting for longevity of land and climate mitigation. The same SME offered the example of Indigo Agriculture, as a intersection between technological innovations and regenerative agriculture.

Indigo Agriculture is a company that is focused on "harnessing nature to help farmers sustainably feed the planet" (Indigo Agriculture, n.d.). Part of this focus area includes founding the Terraton Challenge, a yearly challenge that is geared towards crowdsourcing solutions to regenerative agriculture to advance the Terraton Initiative (University of British Columbia, n.d.), which seeks to sequester 1 trillion tonnes of carbon dioxide from the atmosphere (Gullickson, 2019). Indigo and the Terraton Initiative is focused on fostering a future where farmers and agricultural practices are driving progress on climate action (and emissions reductions) rather than being part of the problem (as they are now). Carbon sequestration removes carbon from the environment while regenerating soil. Workshop participants identified opportunities for AI to automate and improve the efficiency of large-scale sequestration operations to increase the positive impact on natural systems.

Some specific AI systems for agriculture purposes that were highlighted includes RPI Systems and OneNote. A workshop SME in both AI and Agri-foods noted that these companies are developing technologies alongside farmers which is both a competitive advantage to address barriers to technological adoption, and improving the effectiveness of technologies in providing farmers with intelligent insights to inform crop selection and farming decisions to minimize their carbon footprint, improve their soil conditions, enhance the longevity of their land, and mitigate against climate impacts.

Finding opportunities to reuse resources that go into food production, distribution, and consumption.

Resource Optimization

- Leveraging AI to optimize resources and “right-size” rather than maximize production and operational efficiency for growth.

A discussion around the H1 possibilities of AI addressed the current capabilities of AI, and how these might improve resource optimization. A theme that emerged from the H1 discussion was that too much food was produced then wasted, due to the incentives underlying the system. This conversation shifted in H2, when discussing how much food is “enough” and leveraging AI to dynamically “right size” food production based on the needs of the local market. If this is still occurring in the context of a global supply chain, this optimization could be extended to minimize the amount of food wasted based on preservation time, demand for food in different regions, and likelihood of consumption.

A localism theme that emerged during workshop discourse also encompassed the use of AI to track and process data to power resource sharing apps for consumers, which would enable them to share food before it becomes waste. This closes the loop between consumers and producers such that producers can track the path of food until actual consumption, rather than to the point of sale. Further to this, local sharing can strengthen community bonds, and increase the availability and accessibility of food for people of different socioeconomic backgrounds. In times of affordability crisis, applications of AI (and its large-scale data processing capabilities) can empower people to share food with people who need it, before it becomes waste and reduces instances of food insecurity due to lack of funds, hunger, and undernutrition. This addresses the circular goal of closing “leakage points” for waste in the system, by adding a layer of resource capture, post-sale, so that consumer waste is limited. As Parfitt, Barthel, and Macnaughton (2010) revealed in the literature review section, post-consumer waste accounts for the majority for food waste in developed nations, so this application would be particularly impactful in minimizing waste in Canada’s food system. Further to sharing, the group also thought AI optimization could aid in community food planning, to track community food needs and suggest planting options that are a best match for those needs based on environmental conditions, timelines, and community land areas (i.e. community gardens) available.

AI for Resilient Food Systems

Decentralized Food Production

AI for hydroponic/vertical food systems within cities. Scaling the production capabilities to enable a more decentralized food system.

The workshop group identified several technological categories that are currently improving the sustainability of food systems. These include food science applications for lab grown meat and dairy, AI integrations in farming technologies, vertical farming, and hydroponics. This sentiment is echoed by The Prairie Climate Centre, who highlighted the role that local food production plays in building this resilience in cities, but also emphasized the importance of shorter and more localized supply chains, technologies such as hydroponics, aquaponics, and vertical farming (to reduce the demand for soil), and regulatory changes in zoning laws to enable more local agricultural activities within city limits (Temmer, 2017).

Supply Chain Optimization

Predictive AI Addressing Supply Chain Resilience

Another theme that emerged from this discussion was the use of predictive AI and computer vision to minimize food waste and predict food shortage or supply chain issues. These kinds of innovations could improve the resilience of our food systems by adding an anticipatory layer that would enable production to automatically adjust to potential shortages or supply chain issues. AI products that can leverage data from international food supply chain and market demands to predict potential supply chain bottlenecks can increase the competitive advantage of Canadian food producers and retailers and also reduce the amount of wasted products that might come from overstocking or over producing as a response to shortages.

Another layer of data that could enhance this effort is predicting consumer behavior to add further accuracy to food production models with the goal of waste prevention and shortage mitigation. By reducing the distribution margins between food production and consumption, less food is wasted, and food can be better distributed to where it might be needed. This provides a more forward-looking strategy to allocate where food goes and how much is sent.

Local and international food distributors could also be supported with such technologies through insights that would provide the best (least carbon-intensive) route to deliver food from producers to retailers and consumers.

On a smaller scale, AI-enhanced computer vision could predict how long food can stay good, to assist retailers with expiration recommendations and consumers in feeling safe consuming food based on data-driven expiration models (Kakani et al, 2020). As noted in the literature review, companies like Wasteless already occupy this space.

Section 5 - A Resilient and Secure Future

Workshop participants acknowledged that although artificial intelligence can play a key role in enabling resilience and greater food security in our current food systems, changes to values structure and mindsets, that contrast the status quo will be required to transform the future of Canadian food systems into one that is reliably resilient and secure by design.

LASERRS Framework for Future Food Systems

An affinity mapping exercise conducted by the researcher revealed emergent themes from the future which workshop participants co-envisioned during the Horizon Three discourse. From these themes, the researcher created a framework to visualize the core values of this future system, and their alignment with the desired outcomes of food system resilience, food security, and natural regeneration. The LASERRS (Localism, Accessibility, Sustainability, & Ethics for Resilience, Regeneration, & Security) Framework for Food Systems is the synthesis of the discussions participants had to articulate the core values and outcomes of their desired future food systems. This desired future food system would be resilient to future challenges and new threats, environmentally regenerative, and enable food security for Canadians. At the heart of the LASERRS Framework are new, socially-oriented core values: sustainability, ethics, localism, and accessibility, which contrasts the capitalist values which are foundational to the status quo. The LASERRS Framework aligns the core values and desired outcomes of the Horizon Three vision in relation to the desired features, priorities, and patterns of behaviours that arose from workshop discourse: food sovereignty, community, natural harmony, and Indigenous perspectives. This alignment also helps to orient new projects, initiatives, business opportunities, and policy, with the vision of a future food system that is regenerative, resilient, and secure, and to ensure they align with the core values of this future system.

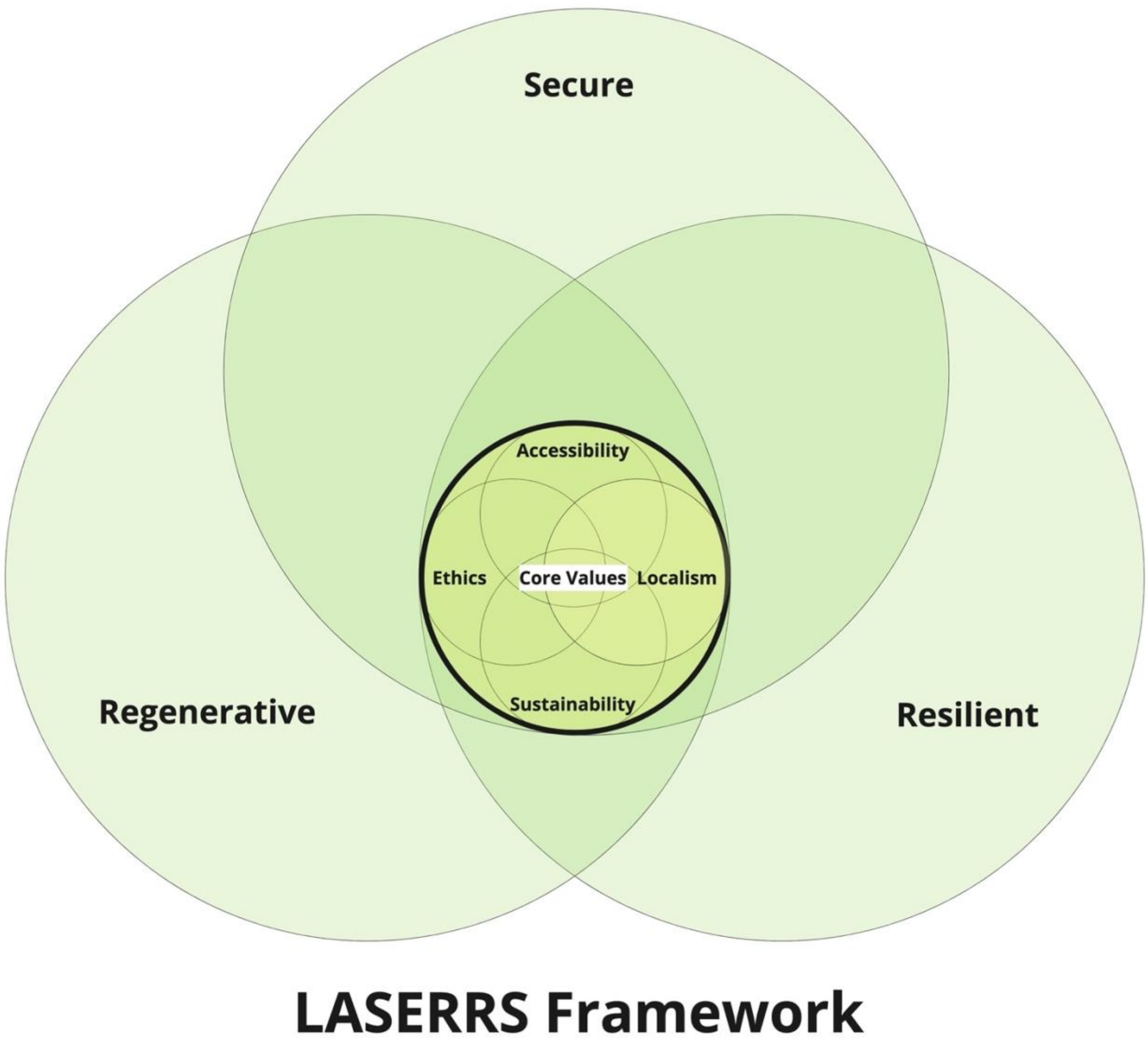

Figure 1 – LASERRS Framework

The LASERRS Framework also aligns with the principles of the circular food system and extends beyond it by placing ethics and accessibility at its core. It was generated from a Canadian context, through a workshop that sought a vision for a food future that would enable resilience and security for the Canadian food system. An important part of the LASERRS Framework that is especially crucial for its Canadian application is its integration of Indigenous perspectives as a path towards continued reconciliation. Although this lies beyond the scope of this research project, it was a point that workshop participants held as a deep desire for the role food systems could play in the future for Canada, so it presents an opportunity for promising future research.

Core Values

In the Horizon Three discussion, the workshop participants expressed a desire for socially-focused core values for a future Canadian food system. These core values include sustainability, ethics, accessibility, and localism. These socially-focused values contrast the capitalist foundation and driving priorities of profit and growth from Horizon One. The expression of these desires informed the synthesis process by placing these values at the core of the LASERRS Framework. The themes that emerged from participant discussions on these values in relation to food systems are as follows.

Sustainability

The workshop participants expressed a desire for sustainability to be a central value for consumers, with the hope that that would drive business decisions for producers. If a majority of consumers opt to support producers who incorporate regenerative practices such as carbon net-negative agriculture, more producers would be incentivized to follow suit, as their economic viability would depend on sustainable practices as opposed to competitive pricing. Furthermore, as the demand for regenerative practices increases, a market for service providers who can help producers pivot their operations would open up, and prices would reduce for these practices. In addition, as sustainable producers grow and scale their operations, as does the benefit to the environment, and living organism living within it.

The workshop participants identified glimpses of this core value in our present, by highlighting a growing awareness of food sustainability among consumers. The hope is that this trend would reach maturity in the future and sustainability-driven purchase decision would become a norm. The participants also emphasized that the premium pricing that comes with sustainable food products excludes many potential consumers based on socioeconomics, which is a point they hope that future food systems might address. This is explored further through the accessibility and localism values, which seek to reduce inequities (highlighted in Horizon One) that our current food systems exacerbate.

Placing sustainability as a core value of future food systems would enable more resilience and security in our food systems by incentivizing and fostering a culture of care over land use, soil health, and long-term crop viability.

Ethics

The participants also expressed a desire for food ethics to be another core value of future food systems. The discussion on ethics explored how future food systems should better align with ecocentrism, labour rights, indigenous reconciliation, and anti-colonial movements.

Ecocentrism goes beyond human centered values and design, by placing the planet at the center of design decisions. In the context of food systems, this would mean considering the impact food production practices have on natural environments, the people working in those systems, and animals as well. This would move our food systems closer to circularity by actively regenerating natural systems as we use them for food production. Participants also flagged the need to consider water use as part of this ecocentric movement, as looming water shortages, which are also driven by climate change, have major implications for communities. Also within the context of ecocentrism, participants discussed how legal rights might be extended to animals and the environment in the future. Legal implications for violating animals and the environment would further incentivize people and businesses to place ethics at the center of their food operations.

The participants noted that adopting an ecocentric ethos would minimize (ideally eliminate) exploitation of workers, especially those in developing nations. Their hope is that a future society would put ethics at the center of their decision making as both consumers and producers. Consumer decisions would drive producer action (as noted in the sustainability section), and as more producers align with new consumer values, the hope is that entrenched labour rights would be a norm within the industry.

Some current social movements that align with the ethical priorities of the food future the group envisioned include indigenous reconciliation, and anti-colonialism/anti-capitalism movements. Anti-colonial and anti-capitalist movements highlight glimpses of a new value and incentive structure which could be major features of future food systems. A major theme in the Horizon One discussion was the driving influence capitalist values had on much of the waste, exploitation, and environmental degradation that food systems are causing and being impacted by. Many participants highlighted how Indigenous reconciliation actions often align with regenerating natural systems and shifting perspectives and ways of operating to a manner more harmonious with natural systems. The group praised the rich history and knowledge that indigenous groups have preserved for several generations, and sought guidance from these communities on how we might better work with our lands in a regenerative and respectful way, as opposed to our unsustainable status quo of extractive and exploitative practices and systems, based on value systems which orient humans as dominant over nature rather than a part of it.

The ethical values outlined above would enable more resilient and secure food systems by placing ecocentric values at the core of food systems, which would promote more regenerative practices. Furthermore, prioritizing the well-being of animals, the environment, and labourers over pure profits would enable more sustainability by enhancing the ability of labourers to work within food systems and add value with their unique front line perspectives. Prioritizing the well being of the environment would naturally lead to more long-term viability of land, which positively impacts food security for local communities that depend on that land for food.

Accessibility

Accessibility as a core value emerged from participant discussions during Horizon Three. In this context, accessibility also includes affordability, as this is a major barrier that participants highlighted for many Canadians from accessing sustainable, nutritious, and ethically produced food. By placing food accessibility (both in terms of affordability and distance) as a core value of the Horizon Three food system, participant sought a future where producers, governments, and communities collaborate to ensure that all members of society share access to food that nourishes them, and is produced through methods that enable longevity of the the biosphere.

Much of the vision for AI in this future involves harnessing it to maximize accessibility, and enable easier access to a wide range of food, closer to the communities that grow and use them. Accessibility is also closely tied to the value of Localism, with the latter also encompassing an ownership aspect that sees communities gain equity in the food they grow and share.

Placing accessibility as core value for future food systems would enable more resilient food systems through the decentralized structure of food production that would emerge from a more accessible food network. This way, the fragile supply chain shocks that wreak havoc in the status quo would be better insulated due to more “food nodes” to deliver and distribute food to communities close by in the event that they are dealing with issues preventing them from accessing their food. By increasing the resilience of food systems through this structure, food security would naturally be improved as well.

Localism

Localism was another core value that workshop participants articulated as crucial to their Third Horizon vision for the Canadian food system. The ability to grow anything anywhere, within fully integrated city systems with food growing capabilities, wherever possible, was highlighted. Technologies like hydroponic systems, vertical farming, and AI were seen as technologies that could be matched to provide this capability.

A current trend which would reach maturity in this future is a growing focus on locally produced foods. This would be enabled to scale in the future, such that local producers are numerous enough to satisfy their community demands. Participants emphasized the importance of local producers and the communities they operate in gaining the majority of equity in the food they produce. This shift in major equity holders (from global multinationals to local producers), demonstrates the localism ethos that contrast the globalist ethos that dominates the food market in Horizon One. The participants saw this shift as a step towards re-distributing wealth from large global corporations, and their shareholders, that profit from economies of scale, to local producers and the communities they serve. This way, wealth flows towards the actors who can best “feed people” rather than the entities that can develop the most efficient farming and distribution operations.

The group saw potential for AI and other technologies to provide capabilities for growing systems to create the conditions to grow any crop in any hydroponic system. An intelligent system that could respond to local needs, and eventually predict them can provide communities with the tools to drive and leverage local production to meet all their food needs. Vertical farming would save land area required for these operations, and could enable these farms to operate at a large scale in urban areas such as subway stations and buildings. These technologies will be explored further in the Technology section.

Workshop participants echoed a desire for a future food system with an ethos of localism, powered by AI and hydroponic operations that could produce any food anywhere, would effectively minimize transportation waste from food systems by reducing the distance from production to consumption, and drastically reduce the carbon footprint of our food systems. This would make a positive impact on climate change, while actively regenerating natural systems (a central principle of the Circular Economy), by adding more growing areas in what was previously a concrete jungle.

Localism as a core value for future food systems would enable more resilience in food systems, by enabling a more distributed supply chain, and reducing the distances food needs to travel to feed people. This would mitigate risks associated with the highly interconnected global supply chain, highlighted in Horizon One, by streamlining the transportation chains. By integrating food in more areas within urban environments, local supply is also better protected by geopolitical events that impact supply/demand ratios, and spikes prices, and therefore enables communities to access more stable prices for food products. Localism also redistributes wealth from large international multinationals, to local producers, which leads to more wealth being re-invested in the communities being served by local food producers. This diversion of wealth flows, would enable communities to further develop their food infrastructure to continue improving its scale of food operations, and increase its food security as a result. Intelligent (AI-integrated) food production within already existing urban structures would enable local systems to anticipate and respond to shortages and supply chain shocks, and therefore enhance resilience and food security by ensuring accessibility to food regardless of external environmental conditions (related to climate change), and aforementioned supply chain shocks that might result due to those environmental conditions.

Defining Features of the Future Food System

During the synthesis of workshop data, an affinity mapping exercise revealed key features that would emerge from the core values articulated by workshop participants. Food sovereignty, community, natural harmony, and the integration of Indigenous perspectives were major themes that emerged from the affinity mapping of workshop discussions.

Food Sovereignty

Food sovereignty refers to the rights of communities to determine and define their own agricultural food production methods and products (Food Secure Canada, n.d.). The workshop participants wanted food sovereignty to be a defining trait of the communities which produce their own food in the Horizon Three food future. They also noted that a focus on food sovereignty has the potential to provide a more diverse range of agricultural methods and products within Canadian communities, and thus increase the resilience of the overall food system. This resilience would be an outcome of the decentralized structure of this future food system that would mitigate the impacts of the more centralized, but highly interconnected and fragile global supply chain that is an outcome of the current emergent system.

Food sovereignty more strongly aligns with the core values of localism and accessibility. It empowers local communities to determine their own food products and production methods, which are culturally appropriate. This would also enhance the accessibility of food within these communities.

Community

Another defining feature of the co-envisioned future food system was empowered communities. This empowerment flows community-centered and community owned food production, that also elevates their food sovereignty. The workshop participants also envisioned a defining trait of this future community as having a celebratory nature towards the food they produce. It is the hope that by involving more people in producing and owning the food that they consume, communities will come together, celebrate, and form more cohesive bonds. This cohesiveness adds to the resilience of food systems at large by strengthening the decentralized nodes that are created from more community-led food production initiatives.

Community ownership, through a vested ownership structure was a format ideated as a funding mechanism for these local food production initiatives. It is unclear how much money and how large communities would have to be, however, there exists possibilities for emerging food technologies and AI to reduce the costs of food production through the efficiencies they provide. This also presents an opportunity for the role the government can play in providing some relief for the capital costs of community food production infrastructure or software development.

A community-centric focus aligns most strongly with the core values of localism, as it entrenches the ability of local communities to determine production methods and gain equity in their food products. This equity would empower local communities to benefit from the wealth transfer from global corporations to local producers.

Natural Harmony

Another theme that emerged from the Horizon Three discourse was the understanding that in the future we would have to be dealing with the impacts of climate change, regardless of actions we take over the next 20 years. The questions over the magnitude and severity of impacts remains, but the time has passed to avoid any consequences. There was an acknowledgement that there would be a need to leverage our understanding of technology and the land to be in better harmony with the changes and adjust to opportunities that emerge and are lost. This might include utilizing new farming opportunities in different geographies, as warming occurs, and dealing with a new climate reality as it emerges. Understanding shifting cycles and seasonality will be key in this future, and AI is a tool that could help in this understanding by providing automation and a predictive capacity. These focus areas intersect with both AI and circular economy principles, as a deeper understanding and capability to adapt to new climate realities will also provide the ability to minimize waste and make the most of the conditions that the climate provides, while actively regenerating natural systems as we use them, and reducing our carbon emissions in the process.

Natural harmony strongly aligns with the core value of sustainability. A sustainable approach to food production, as noted by workshop participants, involves embracing seasonality, and shifting soil conditions, and adjusting crop selection accordingly. This contrasts the status quo, which seeks to maximize revenue from production at the expense of soil health and environmental sustainability.

Indigenous Perspectives

Workshop participants felt that an important part of the future of Canadian food systems was considering Indigenous perspectives, to better enable long-term sustainability, harmony with the environment, and as part of decolonization and reconciliation efforts. As noted, the group highlighted some examples of Indigenous knowledge related to food production, such as the Three Sisters Method and the Seven Generations Principle, which can provide benefits for all of those who share the land. The Three Sisters Methods utilizes three types of seeds of plants that have complimentary benefits for each other as they grow (Mills, 2017). The Seven Generations Principle integrates the perspectives of Seven Generations of people in decisions of communities (Indigenous Corporate Training Inc, 2020).

The two examples of Indigenous perspectives noted above, represent a limited sample of how embracing Indigenous communities and perspectives in future food systems can benefit all Canadians, the environment, and future generations. The workshop participants highlighted that in order to truly and appropriately integrate Indigenous perspectives, more outreach with Indigenous communities would be a necessity. Although this falls outside of the scope of this research project, its represents a limitation, and an opportunity for future researchers to build on this vision of future Canadian Food Systems, using the LASERRS Framework to develop projects or initiatives to better engage and integrate Indigenous communities, and their rich knowledge, in future food systems.

Integrating Indigenous perspectives aligns with the core value of ethics, as it incorporates an ecocentric approach that many Indigenous communities have been practicing for centuries, considers the perspectives of a historically marginalized group in Canada, and it offers an additional pathway for continued reconciliation for the historical traumas Canada's government has caused Indigenous Peoples.

Policy for the New Food System

A major theme from workshop discussions was the calls for policy action to better align with the values that lie at the core of the LASERRS Framework. Although much of the policy discussion centered on food, there was also an understanding that interconnected policies in areas like water use and energy, would impact the sustainability and ethical values that participants sought for future food systems. The conversation around values and the new food future brought to focus the importance of socially oriented food policy as being an ally of this new system. As noted in Horizon One, a major sentiment from participants was that the focus of current food systems was to maximize profits for major corporations in the food industry, rather than actually feeding people. The feeling among workshop participants was that feeding people was an effect of this current system, but the waste it created was a clear indication that feeding was not the priority or a key metric for the system's success. The workshop group sought to flip this value structure in the future, and have a system, and stakeholders within it, whose priority was to actually feed people. A social-focused food policy that could support the new core values at the heart of the LASERRS Framework was a topic of discussion during the Horizon Three Discussion. Some of the features of this food policy includes consideration of food as a basic right, increasing transparency to limit the powers of food lobbies, universal basic income type programs focused on sustainable and nutritious food, land sharing initiatives, subsidies for local and small scale farmers, water use regulations, and a national composting program.

By orienting food as a basic right, the group wanted to see a push to turn the food sector into more of a non-profit space that focused on creating a more equitable food production space, with a local focus, and enabling all people to have equal access to sustainably produced, nutritious foods.

Increasing transparency in the food system across the board was also seen as a priority, and this aligned with the calls to limit the powers of food lobbies, who participants saw as influencing current government policy to benefit the food business more than consumers. A part of this includes initiatives to improve working conditions, including compensation and benefits for workers in the food sector. These initiatives are an extension of the core value of ethics within the LASERRS Framework.

Government subsidies for local and small scale farmers, as well as UBI-style allotments of food for each household were seen as ideals. Land sharing initiatives were mentioned as opportunities to empower smaller scale farmers to compete with larger corporations in the short term. However, the group acknowledged if the future food system is still capitalistic, there should be subsidies for companies that are able to accomplish zero-waste targets and employ ethical and sustainable practices as part of their operations.

Green energy initiatives which promote the use of renewable energy sources can help reduce the overall emissions from our food systems by replacing fossil fuel sources of energy in manufacturing and transportation (food distribution). Policy actions, such as tax credits, that remove the “green premium” from current renewable sources, can increase the prevalence of these sources of energy in food systems, by making them more economically viable at scale.

Water use regulations were highlighted as a key consideration in the future, as water scarcity was noted as a looming threat related to climate change and food. According to the U.S. Department of Agriculture’s Economic Research Service, irrigation accounted for 42% of all freshwater withdrawals in 2015 (USDA, 2022). Therefore, eliminating wasteful use of water throughout food systems will be key in maintaining an adequate supply of water to grow food. Policy considering water use regulations will add resilience to our food systems by ensuring access and availability of water now and in the future. This item also aligns with some technology innovations that are actively minimizing the use of water in food production, to create a more water-efficient food future. These technological innovations will be explored further in Horizon Two.

Participants also articulated a desire for a national composting program to reduce the amount of food waste in landfills while improving soil health. This would fit well within a circular food system as composting designs out waste from the food system, reduces greenhouse gas emissions (methane) associated with landfills, and regenerates soil's nutrient levels to improve its longevity and resilience to erosion by improving water retention (Hu, 2020). A national composting program would also align with the water use considerations outlined above, as it drastically reduces irrigation demands from agriculture. A 1% increase in soil's composted matter can enable soil to hold 20,0000 more gallons of water per acre (Bryant, 2015).

The policies outlined above would move us closer to a circular food system by creating incentive structures for companies to design out waste and pollution from their processes, with a renewed focus on actively regenerating natural systems.

Section 6 - Conclusion

This major research project sought inform businesses and policymakers in identifying strategic intervention points that can generate economic value and enable resilient and secure urban food systems by exploring how AI could accelerate the transition towards circular urban food systems in Canada. A literature review on the problem space – cities, food systems, and climate change- uncovered the importance of cities in the national economy, the concentration of populations (and resource demands) from cities, and the sizable impact food systems play in greenhouse gas emissions (which drive the effects of climate change). This led to a preliminary exploration of potential solutions in the sustainable conceptual frameworks, primary the circular economy, and the role artificial intelligence could play in addressing focus areas of these frameworks. Next, a Three Horizons workshop with a multidisciplinary group consisting of subject matter experts (SMEs) in Agri-foods, urban ecology, biotechnology, critical infrastructure planning, artificial intelligence, circular design, and foresight generated a systemic perspective on the problem space, leverage points impacting the resilience and security of food infrastructure, and the role AI can play in addressing these issues. The group also co-envisioned a resilient and secure future food system to strive for.

The exploration of the problem space highlighted the reinforcing negative feedback loop between our current food systems, and the impacts of climate change. Both the literature review and the insights from SMEs in the workshop reiterate the significant threat that the interconnectivity of our food systems within a global supply chain play, and how direct and cascading impacts of climate change further exacerbates this threat. The workshop group also explored the profit-driven incentives that lead to a more centralization in food production due to economies of scale, supply chain waste due to cosmetic defects in foods, and premiums on ethically and sustainably produced foods. In aggregate, these outcomes are threats to food infrastructure resilience and security, but also act as leverage points for strategic AI interventions to reverse these outcomes and their associated impacts on food system resilience and security. The following leverage points to enable a resilient and secure food system, and the AI interventions which can drive progress in doing so are as follows:

Decentralization of Food Production

- AI-driven automation systems that enable larger scale local food production from hydroponics, aquaponics, and vertical farming operations, reduce the interconnectivity and length of supply chains and decentralize food production through localism.

Environmental Regeneration

- AI-driven automation systems that scale carbon sequestration operations that actively regenerate soil and removes carbon from the air.
- Deep learning AI that assists farmers by providing crop suggestions that optimize for better soil health, current environmental conditions, and climate mitigation measures.

Resilient and Shorter Supply Chain

- Predictive AI to enable more efficient supply chain management to help reduce systemic food waste.
- AI optimizing supply chains to shorten food journey and reduce associated emissions.

Waste Reduction

- AI utilized by retailers to provide dynamic pricing on foods to increase sales prior to expiry and reduce food waste.
- AI harnessed keep food products in use prior to expiry or discarding, by suggesting potential recipes or use cases within the food system.

Incentivizing Ethically and Sustainably Produced Foods

- AI utilized by research scientists to accelerate progress on developing scalable, cost-effective production of new food products and sustainable food production methods such as lab grown meat and dairy, 3D printed foods, and dehydrated foods.

Mitigating Cascading Impacts of Climate Change

- Predictive AI providing early warnings of extreme weather events, diseases, and international food shortages.

A synthesis of themes from the workshop and literature review uncovered an emergent system within which Canadian urban food systems exist, and the specific outcomes that act as leverage points that threaten food system resilience and long-term food security. Workshop SMEs also generated AI innovations in the food system space that can be harnessed as strategic interventions at these leverage points to improve the outcomes that impact resilience and food security. Their vision of resilient and secure food future extends beyond the circular concept by acknowledging the need to place a new set of values at the core of future food systems. These values are entrenched in the LASERRS Framework, which orients Localism, Accessibility, Sustainability, and Ethics as core values driving the motivations of consumers, governments, and the food industry, to enable Resilience, Regeneration, and Security for future food systems. It is important to note that the full realization of the LASERRS Framework requires more than AI interventions and will necessitate collaborative action and mindset shifts from policymakers, consumers, and the food industry. Future research on policy interventions and community action to facilitate the mindset and values shift required for LASERRS will provide new perspectives and solutions to address food system resilience and security in Canada.

Bibliography

Agriculture and Agri-Foods Canada (2022, August 16) Discussion Document: Reducing emissions arising from the application of fertilizer in Canada's agriculture sector. https://agriculture.canada.ca/en/about-our-department/transparency-and-corporate-reporting/public-opinion-research-and-consultations/share-ideas-fertilizer-emissions-reduction-target/discussion-document-reducing-emissions-arising-application-fertilizer-canadas-agriculture-sector

Baldwin, E. (2020, April 28). The Future of Generative Design: Autodesk on Architecture and Machine Learning. ArchDaily. https://www.archdaily.com/938246/the-future-of-generative-design-autodesk-on-architecture-and-machine-learning

Banton, C. (2022, July 3). Just-in-Time (JIT): Definition, Examples, and Pros & Cons. Investopedia. https://www.investopedia.com/terms/j/jit.asp

Belaud, J.-P., Prioux, N., Vialle, C., & Sablayrolles, C. (2019). Big Data for Agri-Food 4.0: Application to Sustainability Management for by-products supply chain. Computers in Industry, 111, 41–50. https://doi.org/10.1016/j.compind.2019.06.006

Bocken, N. M. P., Short, S. W., Rana, P., & Evans, S. (2014). A literature and Practice Review to develop sustainable business model archetypes. Journal of Cleaner Production, 65, 42–56. https://doi.org/10.1016/j.jclepro.2013.11.039

Bryant, L. (2015, May 27). Organic Matter Can Improve Your Soil's Water Holding Capacity. NRDC. https://www.nrdc.org/experts/lara-bryant/organic-matter-can-improve-your-soils-water-holding-capacity

Castro Pena, M. L., Carballal, A., Rodríguez-Fernández, N., Santos, I., & Romero, J. (2021). Artificial Intelligence applied to conceptual design. A review of its use in architecture. Automation in Construction, 124, 103550. https://doi.org/10.1016/j.autcon.2021.103550

Chouinard, P. & Hales, D. (2019). The National Critical Interdependency Model – Volume IV Characterizing the Food Sector (Reference Document DRDC-RDDC-2019-D142). Defence Research and Development Canada.

CiFAR. (n.d). The Pan-Canadian AI Strategy. https://cifar.ca/ai/

City of Toronto. (n.d.). Food Waste. https://www.toronto.ca/services-payments/recycling-organics-garbage/long-term-waste-strategy/waste-reduction/food-waste/

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., & Leip, A. (2021). Food Systems are responsible for a third of global anthropogenic GHG emissions. Nature Food, 2(3), 198–209. https://doi.org/10.1038/s43016-021-00225-9

Ellen MacArthur Foundation. (2019). Artificial intelligence and the circular economy - AI as a tool to accelerate the transition, http://www.ellenmacarthurfoundation.org/publications

Ellen MacArthur Foundation. (2019). Cities and Circular Economy for Food. https://ellenmacarthurfoundation.org/cities-and-circular-economy-for-food

Ellen MacArthur Foundation. (n.d). Food and The Circular Economy. https://archive.ellenmacarthurfoundation.org/explore/food-cities-the-circular-economy

Fan, W., Kongnetiman, S., Walters, P. (2010). Importance of Cities: with emphasis on Canadian urban areas. City of Calgary Corporate Economics.

Food Secure Canada. (n.d.). What is Food Sovereignty. https://foodsecurecanada.org/who-we-are/what-food-sovereignty#:~:text=%22Food%20Sovereignty%20is%20the%20right,injustice%20in%20the%20food%20system.

Goldie, A., Mirhoseini, A. (2020, April 23). Chip Design with Deep Reinforcement Learning. Google AI Blog. https://ai.googleblog.com/2020/04/chip-design-with-deep-reinforcement.html

Gullickson, G. (2019, December 6). Indigo Ag Announces The Terraton Initiative That Pays Farmers For Carbon Sequestration. Successful Farming. https://www.agriculture.com/news/crops/indigo-ag-announces-the-terraton-initiative-that-pays-farmers-for-carbon-sequestration

Hamam, M., Chinnici, G., Di Vita, G., Pappalardo, G., Pecorino, B., Maesano, G., & D'Amico, M. (2021). Circular economy models in Agro-Food Systems: A Review. Sustainability, 13(6), 3453. https://doi.org/10.3390/su13063453

Hu, S. (2020, July 20). Composting 101. NRDC. https://www.nrdc.org/stories/composting-101

Indigenous Corporate Training Inc. (2020, May 30). What is the Seventh Generation Principle? https://www.ictinc.ca/blog/seventh-generation-principle#:~:text=The%20Seventh%20Generation%20Principle%20is,seven%20generations%20into%20the%20future.

Indigo Agriculture. (n.d.). About Indigo Ag. https://www.indigoag.com/about

International Food Policy Research Institute (IFPRI). (2022). 2022 Global food policy report: Climate change and food systems. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/9780896294257

IPCC, 2022: Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–33, doi:10.1017/9781009325844.001.

Kakani, V., Nguyen, V. H., Kumar, B. P., Kim, H., & Pasupuleti, V. R. (2020). A critical review on Computer Vision and artificial intelligence in food industry. Journal of Agriculture and Food Research, 2, 100033. https://doi.org/10.1016/j.jafr.2020.100033

Koppelmäki, K., Helenius, J., & Schulte, R. P. O. (2021). Nested circularity in food systems: A Nordic case study on connecting biomass, nutrient and energy flows from field scale to continent. Resources, Conservation and Recycling, 164, 105218. https://doi.org/10.1016/j.resconrec.2020.105218

Lachacz, A. (2022, June 16). Ottawa invests $5 million in proposed geothermal project in Hinton, Alta. CTV News. https://edmonton.ctvnews.ca/ottawa-invests-5-million-in-proposed-geothermal-project-in-hinton-alta-1.5951020

Lavelli, V. (2021). Circular food supply chains – impact on value addition and safety. Trends in Food Science & Technology, 114, 323–332. https://doi.org/10.1016/j.tifs.2021.06.008

Makowski, E. (2019, July 11). Monoculture farming is not good for bees: Study. Environmental Health News. https://www.ehn.org/monoculture-farming-is-not-good-for-the-bees-study-2639154525.html

Mills, S. (2017, May 24). How To Grow A Three-Sisters Garden. CBC. https://www.cbc.ca/parents/play/view/how-to-grow-a-three-sisters-garden

Moodie, R., Bennett, E., Kwong, E. J., Santos, T. M., Pratiwi, L., Williams, J., & Baker, P. (2021). Ultra-processed profits: The Political Economy of countering the global spread of ultra-processed foods – a synthesis review on the market and political practices of transnational food corporations and Strategic Public Health responses. International Journal of Health Policy and Management. https://doi.org/10.34172/ijhpm.2021.45

Nance, E., Vadnais, A., Hicks, C., & Lawson, T. (n.d.). Insistence on Cosmetically Perfect Fruits & Vegetables. University of British Columbia. https://cases.open.ubc.ca/insistence-on-cosmetically-perfect-fruits-vegetables/

O'Neill, J. (2019, September 20). Corporate Profit Motives Shape Our Food Environment, and It's Killing Us. The Equation. https://blog.ucsusa.org/science-blogger/corporate-profit-motives-shape-our-food-environment-and-its-killing-us/

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: Quantification and potential for change to 2050. Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1554), 3065–3081. https://doi.org/10.1098/rstb.2010.0126

Penarredonda, J.L. (2017, December 15). Could AI help create a meat-free world? BBC. https://www.bbc.com/future/article/20171214-could-ai-help-create-a-meat-free-world

Pimentel, D. (2005). Environmental and economic costs of the application of pesticides primarily in the United States. Environment, Development and Sustainability, 7(2), 229–252. https://doi.org/10.1007/s10668-005-7314-2

PlantVilliage. (n.d.). Artificial Intelligence. https://plantvillage.psu.edu/

Polsky, J.Y., Moubarac, J-C., Garriguet, D. (2020, November 18). Consumption of ultra-processed foods in Canada. Statistics Canada. https://www150.statcan.gc.ca/n1/pub/82-003-x/2020011/article/00001-eng.htm

Poteralski, A., & Szczepanik, M. (2016). The application of artificial intelligence in the optimal design of Mechanical Systems. IOP Conference Series: Materials Science and Engineering, 161, 012040. https://doi.org/10.1088/1757-899x/161/1/012040

Rogers, H., & Srivastava, M. (2021). Emerging sustainable supply chain models for 3D Food Printing. Sustainability, 13(21), 12085. https://doi.org/10.3390/su132112085

Statistics Canada. (2022, February 9). Canada's large urban centres continue to grow and spread. https://www150.statcan.gc.ca/n1/daily-quotidien/220209/dq220209b-eng.htm

Tagkopoulos, I., Brown, S. F., Liu, X., Zhao, Q., Zohdi, T. I., Mason Earles, J., Nitin, N., Runcie, D. E., Lemay, D. G., Smith, A. D., Ronald, P. C., Feng, H., & David Youtsey, G. (2022). Special report: AI Institute for Next Generation Food Systems (AIFS). Computers and Electronics in Agriculture, 196, 106819. https://doi.org/10.1016/j.compag.2022.106819

Temmer, J. (2017). Building a Climate-Resilient City: Agriculture and food security. Prairie Climate Centre. https://climateatlas.ca/building-climate-resilient-city

Thompson, B. & Baker, N. (Host). (2021, June 9). Google AI beats humans at designing computer chips [Audio podcast episode]. In Nature Podcast. Nature. https://www.nature.com/articles/d41586-021-01558-y

Trotta, D. (2022, April 5). Cities are a key cause of climate change, but they can also be key to solving it. World Economic Forum. https://www.weforum.org/agenda/2022/04/cities-driving-climate-change-but-part-of-the-solution-un-report

United Nations. (n.d.). Cities and climate change. https://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities/cities-and-climate-change#:~:text=Rising%20global%20temperatures%20causes%20sea,housing%2C%20human%20livelihoods%20and%20health.

University of British Columbia. (n.d.). The Terraton Challenge by Indigo Ag. https://ires.ubc.ca/the-terraton-challenge-by-indigo-ag/

USDA. (2022, May 6). Irrigation & Water Use. U.S. Department of Agriculture Economic Research Service. https://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/

VelocityEHS. (2022, June 23). Applying Artificial Intelligence and Machine Learning for More Effective MSD Risk Assessment and Reduction. https://www.ehs.com/2022/06/applying-artificial-intelligence-and-machine-learning-for-more-effective-msd-risk-assessment-and-reduction/

Wasteless. (n.d). Sell more with Wasteless. https://www.wasteless.com/retailers